Optimal Network Design to Detect Spatial Patterns and Variability of Ocean Carbon Sources and Sinks from Underway Surface pCO_2 Measurements

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PROJECT SUMMARY
In agreement with the Intergovernmental Panel on Climate Change (IPCC), the *Second Report on the Adequacy of the Global Observing System for Climate in Support of the United Nations Framework Convention on Climate Change (UNFCCC)* concludes that there remain serious deficiencies in the ability of the current global observing systems for climate to meet the observational needs of the UNFCCC. One continuing aspect of the effort to redress the identified deficiency has been to expand the surface ocean pCO_2 measurement program in order to quantify our understanding of the seasonal and interannnual variability of air-sea CO_2 fluxes in the world oceans. While there is a reasonably good understanding of the major sources and sinks of CO_2 based on the sea surface pCO_2 climatology developed by Takahashi et al. (2002), the motivation for this study is to produce the optimal global pCO_2 sampling network design to provide a region-by-region estimate of the sampling required to quantify fluxes of CO_2 to the nearest 0.1 Pg C/year (Fig. 1), updating and expanding the preliminary effort of Sweeney et al. (2002).

International Linkages:
Research strategies for global carbon cycle studies have been developed by various working groups of programs like the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), the International Human Dimensions Program (IHDP), and the Intergovernmental Oceanographic Commission (IOC) working together. Our project is in support of the need for global-scale coordination of international carbon observation and research efforts in order to achieve the goal of a global carbon synthesis. This study fulfills one component of the urgent need to critically assess the overall network of planned observations to ensure that the results, when combined, will meet the requirements of the research community. By providing an optimal network design for a global pCO_2 measurement program, we will directly contribute to the International Ocean Carbon Coordination Project (IOCCP). We will also contribute to regional efforts such as CARBOOCEAN in the Atlantic and the PICES Working Group 13 in the North Pacific that are coordinating observations.

Relationship to NOAA's Program Plan for Building a Sustained Ocean Observing System for Climate: (Objective 8: Ocean Carbon Monitoring Network)
Optimal design of the pCO_2 sampling network design using both the global database of pCO_2 measurements and simulations of future climate from GFDL's Earth System Model will help NOAA cost-effectively develop the infrastructure necessary to build, with national and international partners, the ocean component of a global climate observing

system. The goal of this data and model-based pCO_2 sampling network design is to quantitatively assess the optimum sampling strategy based on the ongoing long-term observational requirements of the operational forecast centers, international research programs and major scientific assessments.

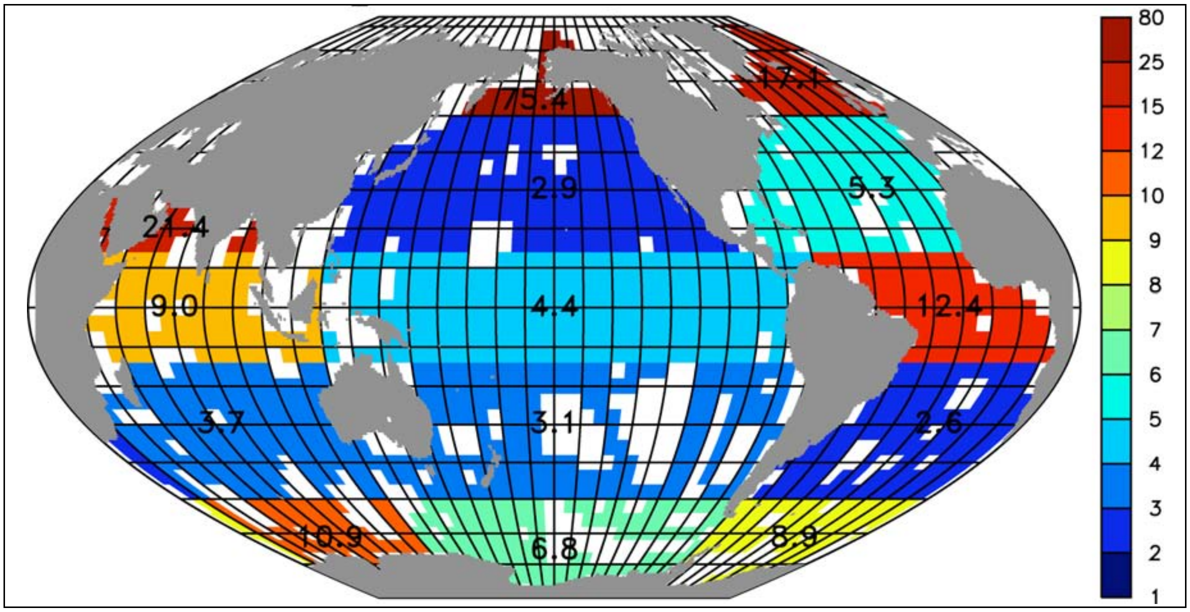

Fig 1. – Target ΔfCO_2 to estimate a regional CO_2 flux within ± 0.1Pg-C/yr for the major oceanic regions.

Specific questions to be addressed include:

- Which seasons most affect the variability of surface pCO2?
- Which sampling locations (boundary currents, open ocean, etc.) will be most representative of large-scale seasonal, interannual and decadal changes in the surface ocean pCO_2 and air-sea CO_2 flux?
- Are there sampling locations that will respond earlier to climate change and will provide the initial detection of changes in surface pCO_2 concentrations and the associated fluxes?

Sweeney et al. (2002) study suggests that a desired uncertainty of ±0.1 Pg C/yr in the basin-scale mean annual estimates for net sea-air CO_2 flux may be achieved by evenly time-spaced measurements of pCO_2 **6–15 times a year** throughout the regions of the world ocean with evenly spaced sampling **200–1500 km apart** (or 2–20 degrees longitude, depending on region and latitude). We have recalculated these targets using both high-resolution measurements made throughout the World Ocean (Fig. 2) and the NOAA/GFDL Earth System Model, and have determined that **4-12 measurements per year**, located **300-1200 km** apart will optimize our sampling network (given the currently available amount of data) to best capture the variability in surface water pCO_2 and the resulting air-sea fluxes on seasonal to decadal time frames.

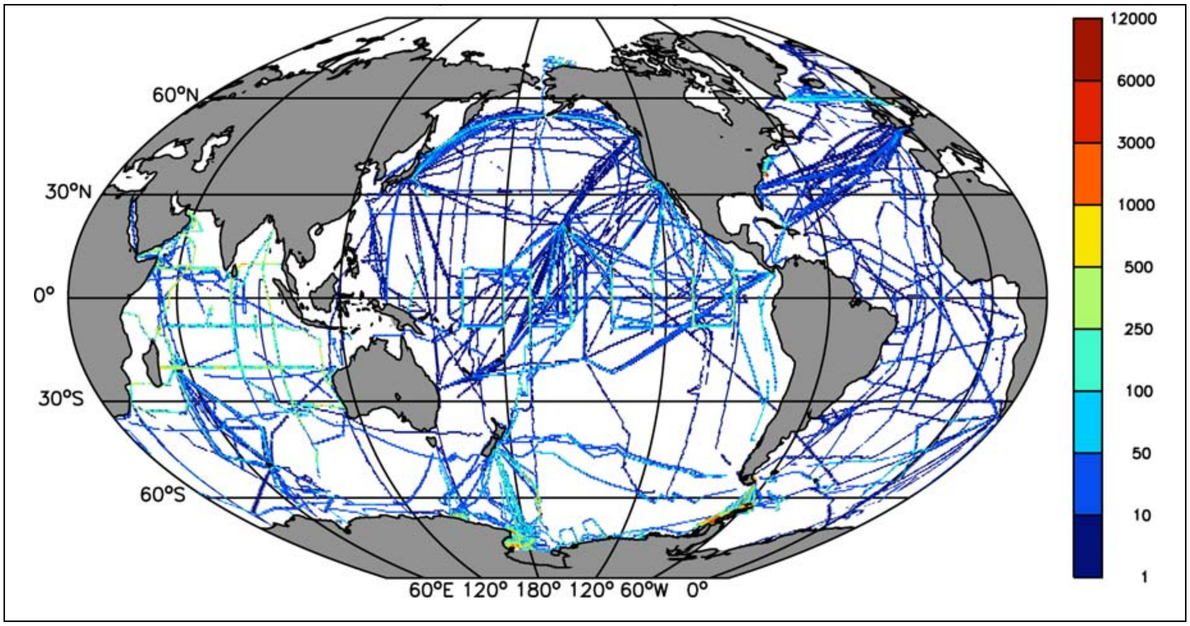

Fig. 2 – Spatial distribution of pCO_2 measurements in the global pCO_2 database. Number of measurements in each 0.5°x0.5° grid.

Ocean Regions	Ocean Area (10^6 km^2)	Average ΔfCO2 (μatm)	Annual Flux (PgC/yr)	ΔfCO2 per 0.1 PgC/yr uptake
Polar North Atlantic	7.05	-45.2	-0.26	17.1
Temperate North Atlantic	23.71	-19.0	-0.36	5.3
Equatorial Atlantic	17.13	11.2	0.09	12.4
Temperate South Atlantic	24.38	-8.4	-0.32	2.6
Polar South Atlantic	9.89	-5.9	-0.07	8.9
Polar North Pacific	5.26	-15.3	0.02	-75.4
Temperate North Pacific	42.01	-19.5	-0.67	2.9
Equatorial Pacific	50.67	17.6	0.40	4.4
Temperate South Pacific	36.50	-15.2	-0.49	3.1
Polar South Pacific	16.53	-12.6	-0.19	6.8
Temperate North Indian	4.15	35.3	0.17	21.4
Equatorial Indian	18.61	13.0	0.14	9.0
Temperate South Indian	26.94	-25.9	-0.70	3.7
Polar South Indian	7.27	-9.3	-0.09	10.9
Global Oceans	290.09	-6.9	-2.32	0.3

Table 1 – Mean annual sea-air fCO_2 difference, annual flux and the sea-air fCO_2 required for 0.1 Pg C flux. All the values are from the assembled fCO_2 database. The long-term mean wind speed data from NCEP and the wind speed dependence of gas transfer coefficient of Wanninkhof (1992) have been used.

Table 1 shows that estimation of a regional CO_2 flux to within ± 0.1 PgC/yr for the major oceanic regions requires that the sea-air fCO_2 difference be determined to within 3 to 12 μatm. Small oceanic regions such as the Polar North Pacific and Temperate North Indian

Oceans (area < 7 x10^6 km^2) fall outside this range since the net flux for these areas are much smaller than 0.1 PgC/yr. The Polar North Atlantic with its high fCO_2 difference and relatively small area also falls outside this range.

FY 2006 PROGRESS

Of the three integrated components of the optimal network design, we have

1.) **Expanded** global pCO_2 database to include new cruises conducted during 2005 and 2006. We have also added much of the as yet unpublished data collected aboard the R/V Nuka Arctica in the North Atlantic (provided by Are Olsen). The data base now contains approximately 2 million measurements
2.) **Completed** the large-scale regional analysis of pCO_2 variability within the global pCO_2 database (Table 1), and have begun the finer-scale temporal and spatial analyses focusing on seasonality and the relative importance of boundary current versus open ocean measurements.
3.) **Continued** analysis of seasonality, length and time scale of pCO_2 variability with the GFDL Earth System Model.